Product Quality Readme file for ERS-1/2 Wind Scatterometer Products

Field	Contents
Title	Readme file for ERS Wind Scatterometer Products
Reference	ENVI-GSOP-EOGD-QD-15-0130, issue 1.2 Date: 28 May 2019
Affected data sets	This readme file applies to the following products: • ASPS20_N (reprocessed data in nominal resolution) • ASPS20_H (reprocessed data in high resolution) • UWI (reprocessed operational data in nominal resolution) • NetCDF Level 2 High and Nominal resolution generated by the Advanced Scatterometer Processing System version 10.04 and the ASPS2NetCDF converter (for the NetCDF format)
Product specification references	Product Specification: ERSE-GSEV-EOPG-RS-06-0002, Issue 2, Revision 4, 29/08/2017
Change log	This document shall be amended by releasing a new edition of the document in its entirety. The table below records the history and issue status of this document.

Issue	Date	Change
1.0	26/03/2015	First issue
1.1	30/08/2017	Updated Product Specifications with NetCDF file format
1.2	28/05/2019	Updated for ERS-1 dataset delivery

Summary

Description

1. ERS AMI Wind Scatterometer Instrument

AMI (Active Microwave Instrument) operated as scatterometer sends microwave pulses under an incidence angle θ to the Earth's surface, and measure the power scattered back, allowing estimation of the normalised radar cross section (σ_o) of the Earth's surface. Over Ocean, the radar cross-section σ_0 mainly depends on the sea roughness, which in turn depends on wind speed and direction (it increases when the wind speed increases). Multiple, collocated, nearly simultaneous σ_o measurements acquired from three directions (i.e. one looking perpendicular to the satellite ground track, one looking forward and one looking backwards at 45° azimuth projection angle with respect to the ground track) can be used to solve simultaneously the minimization of a cost function to retrieve the wind speed and direction. The most widely adopted forward models, used in the cost function, relating σ_o to the wind speed are empirical and are periodically updated and improved based on real satellite measurements.

Table 1: Operating Characteristics of ERS-1 and ERS-2 AMI in Wind Scatterometer mode

	ERS-1	ERS-2
Time Period	25 July 1991 – 03 June 1996	21 April 1995 – 5 July 2011
Frequency	5.3 GHz (C band)	5.3 GHz (C band)
Antenna Azimuth Orientations	Three fixed	Three fixed
Polarizations	V Only	V Only
Beam Resolution	Range Gate	Range Gate
Resolution	25/50 km	25/50 km
Number of pulses per 50 km	256	256
Swath width	500 km	500 km
Incidence Angle	18 – 59 °	18 – 59o
Orbit	Sun-synchronous 780 km altitude 98.52° inclination	Sun-synchronous 780 km altitude 98.52° inclination

The ERS AMI instrument operated in wind scatterometer mode has a spatial resolution of about 25 – 50 Km depending on the incidence angle over a swath of about 500 km. Table 1 lists the operating characteristics of the Wind Scatterometer.

2. ERS-1 Wind Scatterometer Mission Overview

The European Remote-sensing Satellite (ERS)-1 was launched in 1991. It is the first ESA program in Earth observation with the overall objectives to provide environmental monitoring in the microwave spectrum.
The ERS-1 mission ended on March 10, 2000 due to a failure of the onboard attitude control system.
During the 5 years of operations the acquisition repeat cycle has been changed during the various phases of the mission. A brief summary of the main events of the ERS-1 mission and a short description of the various phases is presented in the Table 2 below:

Table 2: Phases of ERS-1 mission

Phase	Start Time	FIRST Abs. Orbit	Cycle	Orbits per Cycle (cycle length in days)
A	25/07/1991 - 10/12/1991	126	1-47	43 (3)
B	28/12/1991 - 01/04/1992	2354	48-80	43 (3)
R	02/04/1992 - 14/04/1992	3735	81-81	501 (35)
C	14/04/1992 - 23/12/1993	3901	83-101	501 (35)
D	23/12/1993 - 10/04/1994	12754	102-138	43 (3)
E	10/04/1994 - 28/09/1994	14302	139-140	2411 (168)
F	28/09/1994 - 21/03/1995	16747	141-143	2411 (168)
G	21/03/1995 - 11/03/2000	19248	144-196	501 (35)

3. ERS-2 Wind Scatterometer Mission Overview

The European Remote-sensing Satellite (ERS)-2 was launched in July 1995 as the follow-on mission to ERS-1 and was concluded with the deorbiting of the satellite on July 2011. Table 1 lists the operating characteristics of the Wind Scatterometer.

During the 16 years of operations, the ERS-2 mission underwent a number of failures (platform and AMI) and consequent changes of both the acquisition plan and the ground segment configuration. A brief summary of the main events of the ERS-2 mission is presented in the Table 3.

Table 3: Main Events of ERS-2 mission [Crapolicchio et al., 2012]

Period	Event
1995, Apr.	ERS-2 is launched on April 21, 1995.
1995, Nov.	The first Scatterometer measurement is achieved by setting the antenna circulator system into an intermediate position to avoid arcing in the AMI transmitter. In this new configuration the transmitted power is reduced by a factor of 3 dB if compared with ERS-1.
1996, Aug.	Due to an anomaly in the internal calibration unit, the calibration sub-system is switched from side A (nominal) to side B (redundant).
2000, Jan	Three of the six gyroscope fail, the operation mode is changed from Nominal to Mono-Gyro Mode. In Mono-Gyro configuration the accuracy of the satellite attitude was degraded in particular for the yaw angle.
2001, Jan.	Other two gyroscopes fail, leading to the so-called Zero-Gyro Mode; the single operating gyroscope is only used for important orbital manoeuvres. Scatterometer operational data is degraded and are not disseminated to the users. More details can be found in the list of events affecting ERS-2 Scatterometer mission at https://earth.esa.int/web/sppa/mission-performance/esa-missions/ers-2/scatterometer/mission-highlights.
2001,Jun.	To test a way to compensate for the gyroscopes failure, ERS-2 AMI starts operating only in Wind-Wave acquisition mode.
2003, May	Nominal Wind Scatterometer acquisition mode is resumed.
2003, Aug.	ERS Scatterometer Attitude Corrected Algorithm (ESACA) is included in the processing chain to compensate for the switching off of the gyroscopes.
2010, Sep.	Due to an irrecoverable transponder failure, the calibration acquisition mode is removed from the orbital planning and substituted by nominal acquisition.
2011, Feb.	ERS-2 is lowered by a series of orbit manoeuvres. As a consequence of that, the repeat cycle changes from 35 to the 3 day.
2011, Jul.	ERS-2 is decommissioned.

4. ERS Wind Scatterometer processor Version 10 .04

To satisfy the needs of high quality and homogeneous set of Scatterometer measurements, the European Space Agency (ESA) has developed the processor Advanced Scatterometer Processing System (ASPS) with which a long-term dataset of new ERS-1 and ERS-2 wind products, with an enhanced resolution of 25km square, has been generated for the entire ERS mission [Crapolicchio et al., 2004].
The Wind Scatterometer/ERS-2 ASPS processor version 10.04 introduces a number of upgrades that are detailed in this document. Detailed information can be found here.

4.1 Processor upgrades

The new ASPS Level 2 data set includes significant quality improvements with respect to the previous UWI operational data version:

- re-fined calibration of the 3 backscattering measurements (σo),
- retrieved wind vectors characterized in terms of CMOD5N [Hersbach, 2008] (neutral wind) geophysical forward model derived by ECMWF, 4 aliased wind vector solutions (Rank 1-4) and de-aliased wind vector flag,
- sea-ice probability and sea-ice flag,
- YAW error angle flag to be used as quality indicator filter during the Zero Gyro Mode (ZGM) period from 2001 till the end of the ERS-2 mission.

The auxiliary files which have been used as inputs for processing wind-scat data are the following:

- Geophysical information files
- LUT Look Up Table

The following geophysical auxiliary files have been used as background information for the wind ambiguity removal:

ERA-40 (ECMWF 40 Year Re-analysis) until August 2002
OPAN (ECMWF OPerational ANalysis) from September 2002

The ERA-40 project is a global atmospheric reanalysis provided by ECMWF of many conventional observations and satellite data streams for the period September, 1957 - August, 2002. Analyses were produced daily at 00, 06, 12 and 18 UTC. The atmospheric model was run with the following resolution:

- 60 levels in the vertical;
- T159 spherical-harmonic representation for basic dynamic fields;
- a reduced Gaussian grid with approximately uniform 125km spacing for surface and other grid-point fields.

The OPAN files are equivalent to the ERA-40 and are operational forecasts computed using the same model on daily basis.
The Look Up Tables (LUTs) contain auxiliary parameters used in the ground stations processing, configuration and calibration parameters.
The above files permit to generate ASPS15, ASPS20, UWI, and HEY products.

4.2 ASPS version 10.04 data set

Three different kinds of products are generated with ASPS:

- *Level 1.5* products, that are engineering products not available to the end users;

- *Level 2.0 nominal resolution* products (ASPS20_N – distributed also in NetCDF format), which contain, for each node, the three values of σ0 related to the three beams of the instrument, the retrieved wind (up to 4 solutions for each node)

using the CMOD5N, the ambiguity removed wind solutions, the sea-ice probability, the sea-ice flag and the yaw error flag. The grid spacing of the nodes is 25 Km and the node spatial resolution is 50x50 km square;

- *Level 2.0 high resolution* products (ASPS20_H – distributed also in NetCDF format), which has the same content of the nominal resolution products. The grid spacing of the nodes is 12.5 Km and the node spatial resolution is about 25x25 km square;

- *User Wind* products *(UWI)*, which contain, for each node, the three values of σ0 related to the three beams of the instrument, the retrieved ambiguity removed wind solution using the CMOD5N. The grid spacing of the nodes is 25 Km and the node spatial resolution is 50x50 km square.

The standard ASPS product available for the users is the *Level 2.0 product*. ASPS generates an intermediate product for Quality control (QC) and instrument assessment called ASPS level 1.5. To maintain the compatibility with the actual ERS ground segment one additional output from ASPS is the nominal UWI product generated in NRT since the beginning of the mission.
The Wind Scatterometer Level 2.0 dataset (for both H and N resolution) has been converted also in NetCDF format and it is available to the users through ESA Fast Registration.

4.3 HEY (Helpful ESOC Yaw product)

The HEY (Helpful ESOC Yaw) product represents the "near real time" yaw error angle information retrieved by using Scatterometer raw data plus some auxiliary data generated by the WS processor.
The yaw error angle estimation is computed on-ground by the ESACA processors. The full set of results of the Yaw processing is stored in an internal ESA product named HEY (Helpful ESA Yaw). The estimation of the Yaw error angle is based on the Doppler shift measured on the received echo (first three plots for the Fore, Mid and Aft antenna) and aims to compute the correct acquisition geometry for the three Scatterometer antenna throughout the entire orbit. The Yaw error angle information is used in the radar equation to derive the calibrated backscattering (σ_o) from the Earth surface and to select the echo samples associated to each node in the spatial filter.
Strong degradation in the evolution of the Yaw angle impacts the quality of the σ_o. In such cases a flag in the product allows user to discard the measurements. It was also noted that a strong solar activity impacts the Yaw performances.

4.4 ASPS Product Format

The Level 2.0 product is generated for both *nominal* and *high resolution* and is structured as follow [Crapolicchio and Lecomte, 2004]:
• MPH (Main Product Header)
• SPH (Specific Product Header)
• DSR (Data Set Record)
The detailed description of the product format is available here:

ERSE-GSEV-EOPG-RS-06-0002, Issue 2, Revision 5, 29/08/2017.

5. ERS-1 Wind Scatterometer Calibration Performance

A calibration activity over ERS-1 data has been performed in order to compute a refined in-orbit antenna pattern to be used for the Scatterometer mission reprocessing. The refined in-orbit antenna pattern computed has been compared with the previous one.

5.1 Reference Area

The tropical rain forest in the South America has been used as reference distributed target to monitor the relative calibration and antenna pattern of ERS-1 scatterometer. The target at the working frequency (C band) of ERS-1 Scatterometer acts as a very rough surface, and the transmitted signal is equally scattered in all directions. Consequently, for the angle of incidence used by ERS-1 Scatterometer, the normalized backscattering coefficient (σ_o) will depend solely on the surface effectively seen by the instrument:

$$S^0 = S \cdot cos\theta$$

With this hypothesis it is possible to define the following formula:

$$\gamma^0 = \frac{\sigma^0}{cos\theta}$$

Using the above equation, the σ_o backscattering coefficients over the rain forest is independent of the incident angle, allowing the measurements from each of the three beams to be compared. The test area used for monitoring ERS lies within 15°S-13°N and 80°W-45°W. For a more detailed description of the rain forest area see the IDEAS+-SER-IPF-REP-2992_SCATT_ERS1_Full_Mission_Reproc_Report.
That area was only partially covered by the Regional mission scenario during a period close to the end of the mission allowing a long-term comparison of the antenna profile.

5.2 The refined in-orbit antenna pattern

The analysis of the σ_o over the rain forest evidenced a periodic annual oscillation of the σ_o histogram. The antenna pattern has been analysed dividing the dataset between ascending and descending passes and as function of the month of the year considered: Months from December to May corresponding roughly to the period of maximum in the annual oscillation of the σ_o and April to November. The antenna patterns show a flat profile, within 0.3 dB, for both ascending and descending passes, the new reprocessing with ASPS have improved the stability of the antenna patterns for the maximum curve and for the higher incidence angles, particularly clear for the for-aft beam in the descending passes. Some residual variation of the antenna pattern is still present for (smaller than 0.2 dB) for the mid beam and for the angle smaller than 25°.

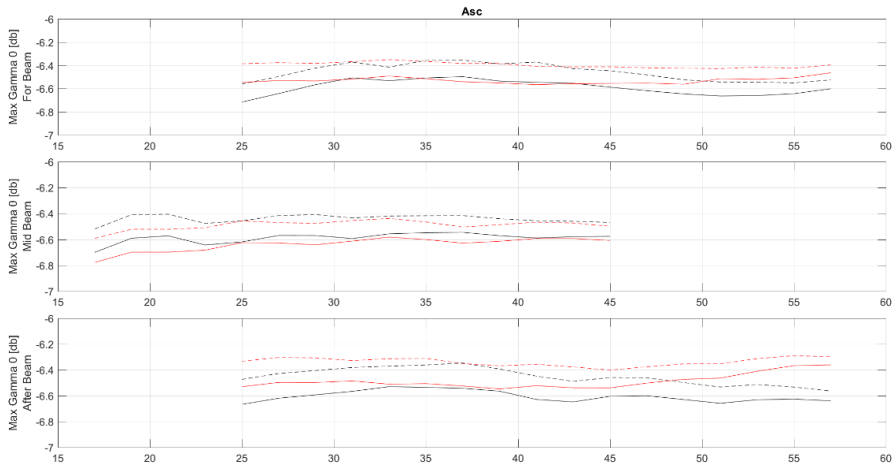

Figure 1 Antenna patterns for ascending orbits as function of the incident angle for the full ERS-1 mission over the rain forest

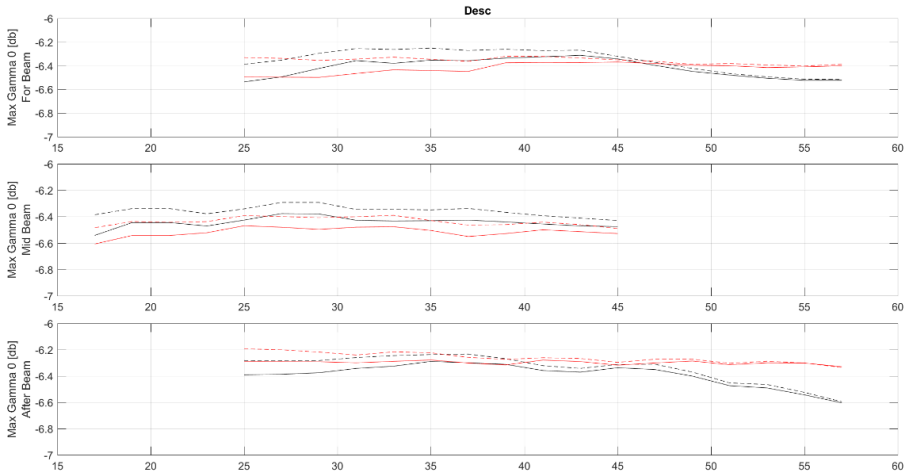

Figure 2 Antenna patterns for descending orbits as function of the incident angle for the full ERS-1 mission over the rain forest

6. ERS ASPS version 10.04 reprocessed data set availability

ERS-1 AMI Wind Scatterometer data set has been reprocessed covering the period from 1st August 1991 to 2nd June 1996 (end of mission).
The size of the available data is: ~290 GB of ASPS_H (also in NetCDF format), ~70 GB of ASPS_N (also in NetCDF format), and 33 GB of UWI.

ERS-2 AMI Wind Scatterometer data set has been reprocessed covering the period from 26th March 1996 to 4th July 2011 (end of mission).
The size of the available data is: 804 GB of ASPS_H (836 GB in NetCDF format), 189 GB of ASPS_N (196 GB in NetCDF format), and 95 GB of UWI.

The reprocessed data asset is available to users through ESA Fast Registration.

6.1 ERS-1 ASPS version 10.04 reprocessed data set caveat

Please find below a list of caveats, which might affect the intended data usage.

- **Cycle 1-3:** the initial period of the ERS-1 mission from 13th July 1991 to 1st August 1991 was not reprocessed due to the limited availability of the AMI in Wind Scatterometer mode.
- **Specific Product Header caveats**: in the SPH in both ASPS and NeCDF format in both H and N resolution the fields:
    - number_of_nodes_with_low_wind
    - number_of_nodes_with_high_wind
    - number_of_nodes_with_internal_calibration_flag_set
    - absolute_orbit_number

  Should be ignored by the user.

- **Missing Orbits:** can be present inside a data cycle (i.e. 35 days of data acquisition). The mission operation overview webpage reports the events that were affecting the ERS-1 Wind Scatterometer mission. Explained missing orbits cannot be recovered because is effectively data lost due to platform/instrument anomalies, and acquisition errors. Unexplained missing orbits might be recovered during next reprocessing campaign and are mainly due to corruption occurred during the transcription processes of the raw telemetry data from tape units to hard disks.

6.2 ERS-2 ASPS version 10.04 reprocessed data set caveat

Please find below a list of caveats, which might affect the intended data usage.

- **Cycle 1-9:** the initial period of the ERS-2 mission from 15th May 1995 to 25th March 1996 was not reprocessed due to the limited availability of the AMI in Wind Scatterometer mode.

- **Cycle 69 to Cycle 74:** data set has been reprocessed but is not available to the users due to degraded calibration performances in the Aft beam antenna measurements. As a consequence of this issue, the Aft beam measurements for those specific cycles will be re-calibrated and the affected cycle will be reprocessed at a later stage.

- **Missing Orbits:** can be present inside a data cycle (i.e. 35 days of data acquisition). At this Web Page are present reports tables with the number of orbits available per cycle and the number of explained and unexplained missing orbits. Explained missing orbits cannot be recovered because is effectively data lost due to platform/instrument anomalies, and acquisition errors. Unexplained missing orbits are mainly due to corruption occurred during the transcription processes of the raw telemetry data from tape units to hard disks.

7. References

- S. Abdalla, G. De Chiara and H. Hersbach, 2011: The technical support for global validation of ERS wind and wave products at ECMWF (July 2008 – July 2011). ECMWF Technical Report.

- R. Crapolicchio, G. De Chiara, A. Elyouncha, P. Lecomte, X. Neyt, A. Paciucci, and M. Talone, 2012: ERS-2 Scatterometer: Mission Performances and Current Reprocessing Achievements. *IEEE Trans. Geoscience and Remote Sensing*, vol. 50, n. 7, pp 2427-2448.

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- F. Polverari, M. Talone, R. Crapolicchio, G. Levy, F. Marzano, 2013: characterization of ocean wind vector retrievals using ERS-2 high-resolution long-term dataset and Buoy measurements. ESA living Planet, Edimburgh (UK).

8. Acronyms and Abbreviations

AMI	Active Microwave Instrument
ASPS	Advanced Scatterometer Processing System
CMOD-5	CMOD-5 C-band Model 5
DPQC	DPQC Data Processing Quality control
DSR	Data Set Record
ECMWF	European Centre for Medium-term Weather Forecast
ERS	European Remote-sensing Satellite
ESA	European Space Agency
ESACA	ERS Scatterometer Attitude Corrected Algorithm
HEY	Helpful ESOC Yaw
IPF	Instrument Processing Facility
LUT	Look-Up Table
MDS	Measurement Data Set
MPH	Main Product Header

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<table>
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<tr><td>TOSCA</td><td>Tools for Scatterometer Calibration</td></tr>
<tr><td>SPH</td><td>Specific Product Header</td></tr>
<tr><td>UWI</td><td>User Wind products</td></tr>
<tr><td>WSP</td><td>Wind Scatterometer Processor</td></tr>
<tr><td>YSM</td><td>Yaw Steering Mode</td></tr>
<tr><td>ZGM</td><td>Zero Gyro Mode</td></tr>
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<tr><td>WWW References</td><td>

Mission Operations Overview:

ERS-1
ERS-2

Processors documentation can be found here
ERS-2 Telemetry data can be found here (with AMI Operational modes, and Antenna Temperature)

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